Performance Demonstration of Significant Availability Improvement in Lithography Light Sources using GLX™ Control System

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ABSTRACT

Increasing productivity demands on leading-edge scanners require greatly improved light source availability. This translates directly to minimizing *downtime* and maximizing *productive time*, as defined in the SEMI E10 standard. Focused efforts to achieve these goals are ongoing and Cymer has demonstrated significant improvements on production light sources.

This paper describes significant availability improvements of Cymer light sources enabled by a new advanced gas management scheme called Gas Lifetime eXtension™ (GLX™) control system. Using GLX, we have demonstrated the capability of extending the pulse-based interval between full gas replenishments to 1 billion pulses on our XLA light sources, as well as significant extension in the time-based interval between refills. This represents a factor of 10X increase in the maximum interval between full gas replenishments, which equates to potential gain of up to 2% in productive time over a year for systems operating at high utilization.

In this paper, we provide performance data on extended (1 billion pulse) laser operation without full gas replenishment under multiple actual practical production environments demonstrating the ability to achieve long gas lives with very stable optical performance from the laser system. In particular, we have demonstrated that GLX can provide excellent stability in key optical performance parameters, such as bandwidth, over extended gas lives. Further, these stability benefits can be realized under both high and low pulse accumulation scenarios.

In addition, we briefly discuss the potential for future gas management enhancements that will provide even longer term system performance stability and corresponding reductions in tool downtime.

Keywords: laser, availability, gas, management, control

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1. INTRODUCTION

Advanced lithographic processes require high performance from all scanner subsystems, including the light sources. Leading edge light source products have been successful in delivering the required performance. However, increasing productivity demands on leading edge scanners constantly insist on light source availability improvements. Therefore, as light source products mature, their manufacturers have an additional responsibility to deliver improved product availability.

The SEMI E10 standard, illustrated in Figure 1, defines downtime to include preventative maintenance and replacement of consumables, such as light source chambers and optics. The two blue downtime boxes denote the total time lost (downtime) due to module replacement, while the green standby box indicates non-productive manufacturing time that includes Halogen gas refills.

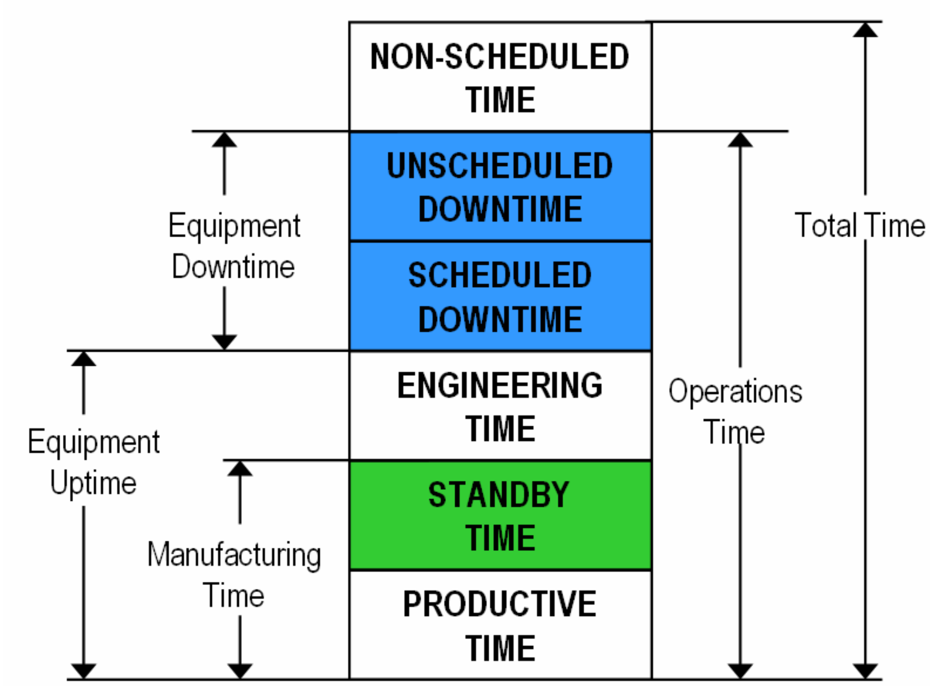

Figure 1: Breakdown of SEMI E10 standard (*Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability*.)

Cymer's ongoing commitment to improved light source availability has yielded 0.2% availability improvement in recent years, through a combination of several techniques. The techniques include direct technology improvements, in-situ process adjustments (such as module replacement procedure improvements), and scheduling optimization for maintenance events.

Cymer spent over two years of research and committed several test lasers to the problem of halogen gas control, understanding that improvements in this area had significant potential to increase availability. As a result of this effort, Cymer recently realized this potential for availability improvement through a 10X reduction in complete halogen gas replenishment events, which require the laser to stop discharging for up to thirty minutes. The new product, called Gas Lifetime eXtension™ (GLX™) control system has been deployed for beta testing at scanner manufacturers and chip-makers, and has provided immediate measurable improvement in light source availability under challenging production environments. GLX's success during these tests, shown in the next sections, stimulated its rapid further propagation into additional sites, which promises to dramatically improve scanner productivity.

This paper describes GLX, demonstrates its performance in production environments, and estimates the resulting productivity improvement. It also briefly discusses ongoing developments in halogen gas control schemes.

2. DESCRIPTION OF GLX™ CONTROL SYSTEM

Cymer lasers employ one or more halogen gas filled chambers as the gain medium. As the light source operates, efficiency is reduced because the halogen gas is depleted and contaminants accumulate. Reduced efficiency can be observed through an increase in the discharge voltage required to create constant pulse energy. Because the discharge voltage has an upper limit, periodically the halogen gas must be replenished and contaminants removed.

Gas replenishment can be done for any fraction of the total gas, up to full chamber replenishment, called a refill. Refills are to be minimized because they can take significant time and therefore cause a large disruption to both laser and scanner operation. However, the benefit of a refill is that it fully replaces the halogen gas and removes nearly all contaminants. A compromise between these competing factors is necessary.

GLX™ achieves this compromise through the confluence of several technology advancements, including cleaner discharge chambers (which generate fewer contaminants), improved component reliability, new signal processing techniques, and advanced gas control algorithms.

The GLX control algorithm includes the concept of contaminant control. Figure 2 illustrates the control paradigm used in Cymer's XLA and XLR series lasers. By combining new signal processing to properly interpret laser signals with advanced control algorithms, GLX computes the precise required amount of halogen (ΔF2) and buffer gas (ΔArNe) required for a partial gas replenishment event. Using several enhancements to low level gas handling, GLX very accurately controls the amounts of gas that are replenished. This precise and accurate control enables the state of the chamber gas to be maintained over long periods while maintaining the short term and long term light source performance to specification.

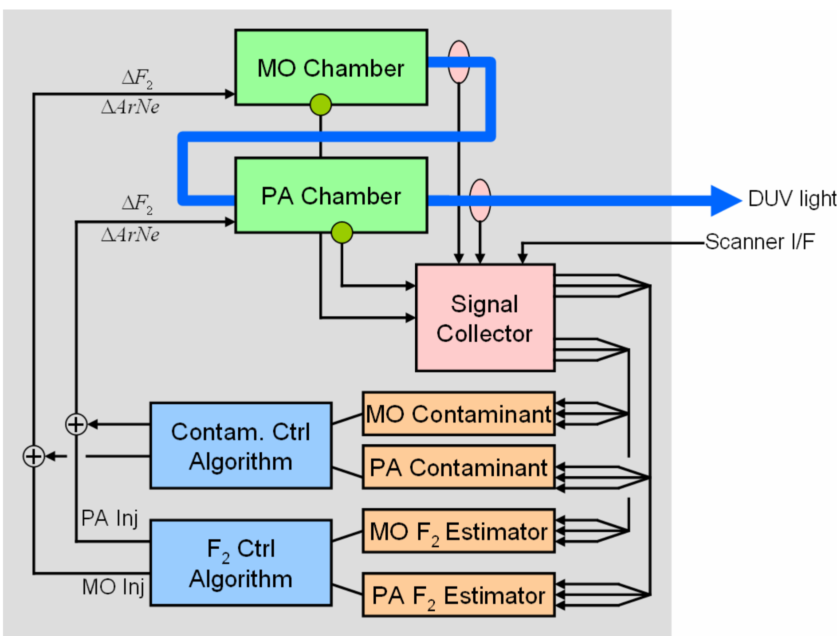

Figure 2: GLX Control System.

With all of these improvements, GLX™ has been able to increase the time between full gas refills by 10X, from 100 million pulses to 1 billion pulses.

To further leverage the increased time between full gas replenishments, Cymer has also increased required calibration intervals. This ensures that calibration intervals remain a proportionally less significant factor in light source availability. This increase was achieved through stricter manufacturing procedures and tighter material and manufacturing tolerances.

3. GLX™ PERFORMANCE

GLX™ has been deployed to several wafer production sites for beta testing and has been operating for several months without problems in challenging environments. Performance has been excellent. Some examples of the performance are given here.

Good measures of laser performance are discharge voltage and output bandwidth. The voltage indicates laser efficiency, with higher voltage implying lower efficiency. Bandwidth indicates laser optical performance. Typically, users desire bandwidth to remain steady, and lower bandwidth is usually better. Both of these measures also reflect the state of the discharge gas, particularly over periods of 100 million to 1 billion pulses.

Figure 3 shows performance of a 4 kHz XLA series laser running at high utilization at a large semiconductor production facility, over a period of 5.5 billion pulses. The laser was changed to GLX operation in the middle of the period as shown. Prior to GLX, the signals were acceptable, but sometimes varied substantially over both short and long periods, and showed transient behavior due to the refill events. After GLX, signal stability is good, even across the refill events. This indicates that the chamber gas state is well maintained. Occasional sharp increases in voltage are attributed to routine laser power down events, typically initiated by the user or scanner. Some slight long-term rise in voltage and bandwidth can be attributed to the accumulation of pulses on consumable modules.

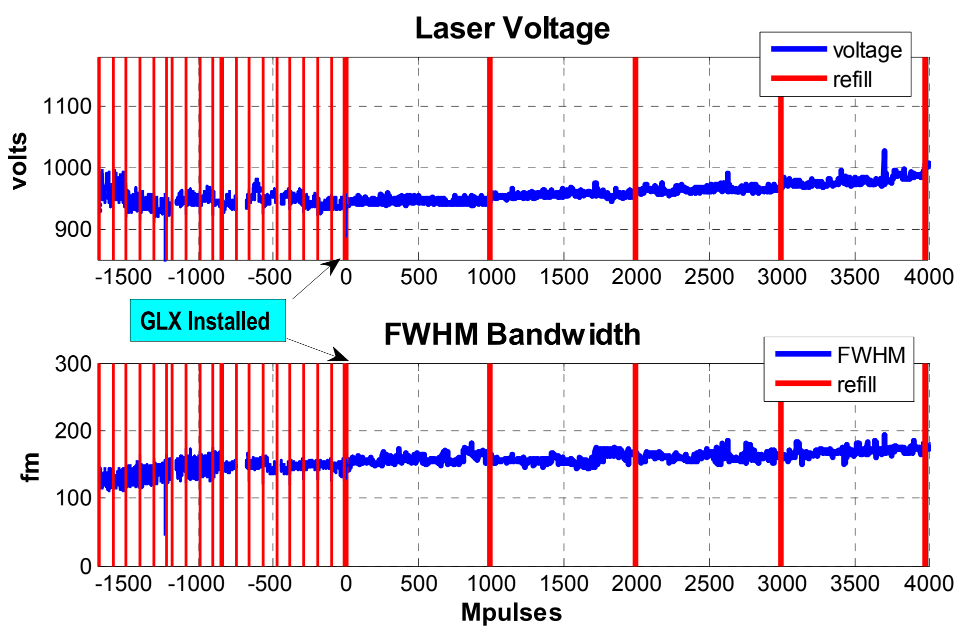

Figure 3. Cymer GLX performance on a high-utilization production XLA laser.[2]

[2] For the data shown, this laser was averaging 87.7 Mpulses/day, or 32 Bpulses/year.

Figure 4 shows performance on another 4 kHz XLA series laser running at high-utilization at a second large semiconductor production facility, over a period of more than 4 billion pulses, where again operation was changed to GLX™ in the middle of the period. GLX performance is also excellent, and compares favorably against pre-GLX performance. In particular, the pre-GLX performance shows variability in voltage and bandwidth, while GLX performance removes almost all of this. Bandwidth rise under GLX is effectively zero.[3]

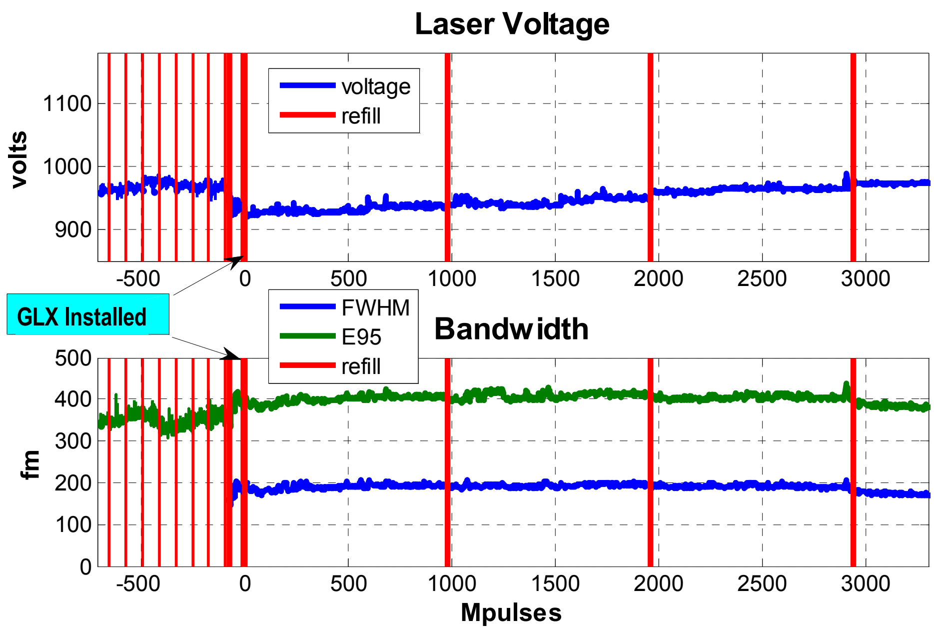

Figure 4. Cymer GLX performance on a second high-utilization production XLA laser.[4]

Figure 5 shows GLX performance on a third 4 kHz XLA series laser, running at a generally low utilization at a third large semiconductor production facility, over a period of more than 1.2 billion pulses, which occurs over more than 25 days. (Pre-GLX data was not available for this laser.) Again, note the lack of transients and almost negligible rise in voltage. Superior bandwidth stability is also demonstrated. The relatively low pulse accumulation rate on this laser is important because it shows that GLX is generally insensitive to pulse rate. For the laser shown in Figure 5, a full gas replenishment (refill) would be required at approximately 3 week intervals, necessitating about 18 refills per year. GLX has no fixed time limit between required full gas replenishment events.

[3] E95 and FWHM are two different indicators of bandwidth. Both measurements are not always are available.

[4] For the data shown, this laser was averaging 111.6 Mpulses/day, or 41 Bpulses/year.

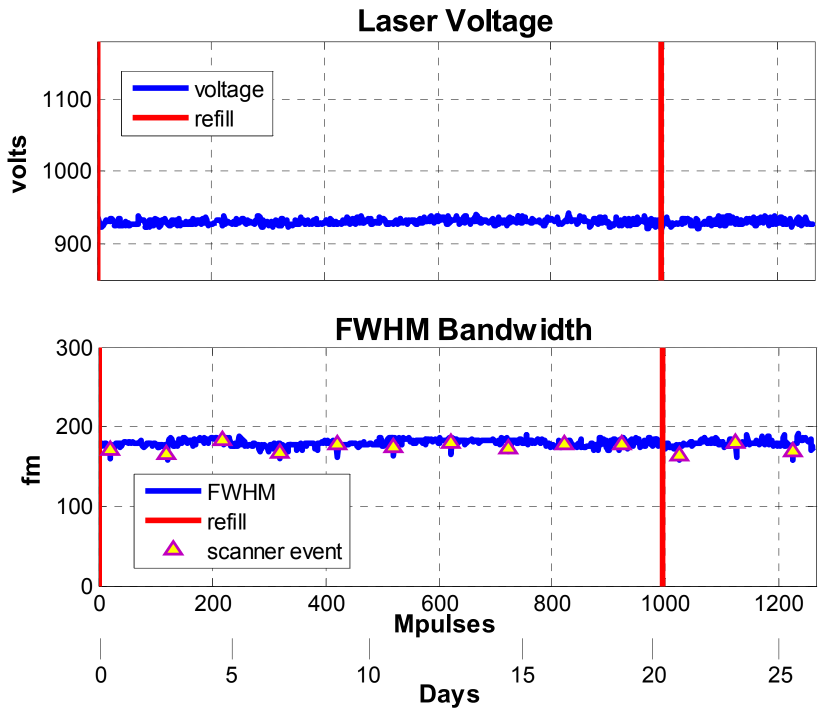

Figure 5. Cymer GLX performance on a low-utilization production XLA laser.[5]

Figure 6 shows GLX performance on Cymer's new XLR™ series laser during recent testing at Cymer's facility in San Diego, California.[6] The recent San Diego wildfires disrupted some of Cymer's facilities, causing laser anomalies, which are denoted in Figure 6. Additionally, before each refill event, the laser underwent system characterization and health checking, demarcated by multiple refills and some fluctuating signal readings. However, the signals' values after these periods are nearly equal to their values before them, indicating GLX maintained gas state well, even across large disturbances.

[5] For the data shown, this laser was averaging 48.1 Mpulses/day, or 17 Bpulses/year. Also note the scanner events depicted in this figure. . The scanner initiated these periodically, and can result in slight disruption of laser operation, which GLX recovers from very quickly.

[6] GLX is a standard feature of XLR Systems.

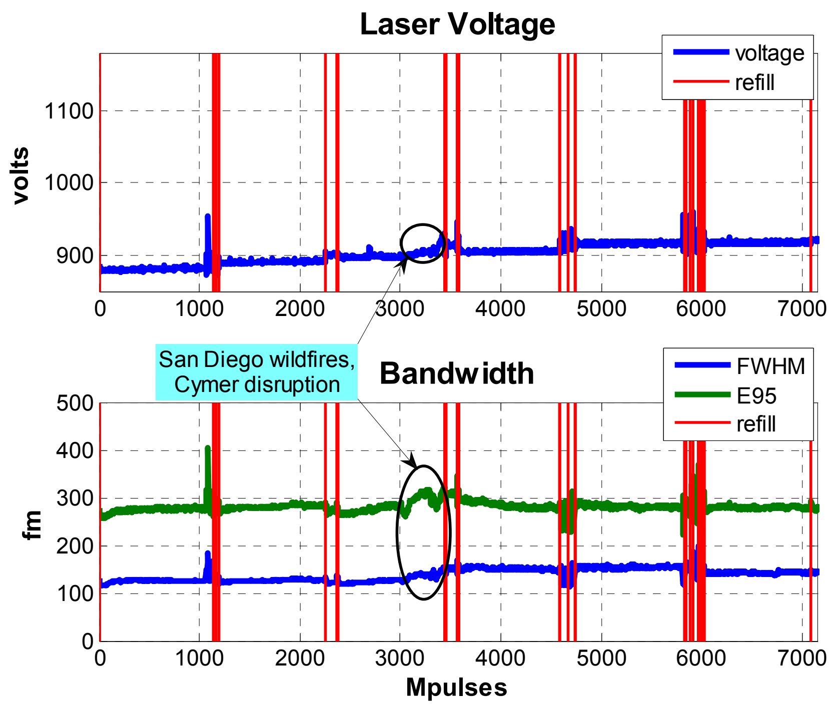

Figure 6. Cymer GLX™ performance on XLR series laser at Cymer facility in San Diego, California

Figures 3 through 6 show that GLX maintains laser performance throughout a one billion pulse interval between full gas replenishments (refills). Additionally, there are no performance transients resulting from the refills, indicating that the laser's gas state is held relatively steady throughout a gas life, and indeed throughout many consecutive gas lives. Laser efficiency (indicated by voltage) and optical performance (indicated by bandwidth) show only slight degradation, which is attributed to the aging of consumable modules. Finally, GLX shows improved stability, particularly in bandwidth, over pre-GLX performance.

Note that GLX is essentially a pulse-based system, where the need for gas replenishment is determined primarily by the number of pulses the laser accumulates. There is no fixed time interval that determines the gas replenishment interval. Therefore, GLX will also operate on very low utilization systems, where the laser experiences long periods of standby (powered on but not discharging). This enables GLX to be deployed successfully in the widest possible array of production environments.

The challenging nature of high volume wafer production and the demands it places on the light source further attest to the capability of GLX in light of Figures 3 through 5. Variations in laser firing pattern and desired output energy naturally cause fluctuations in laser signals. GLX is shown to be insensitive to these over billions of pulses.

4. BENEFIT OF GLX™

The goal that GLX achieves is the increase in productivity of scanners, and ultimately of entire semiconductor production facilities. To quantify this benefit, Table I provides a realistic estimate of the increase in wafer production when using GLX. Although typical usage is near 15 billion pulses per year, the lasers represented in Figures 3 and 4 are significantly higher than this, further increasing the listed benefits.

The benefits shown in Table I clearly establish GLX as an important new technology to the lithography industry.

Average Yearly Pulse Usage on XLA	Average Yearly Increase in Productive Time	Average Yearly Increase in Wafer Production
5 Bp	15 hrs	**1451 wafer passes**
10 Bp	30 hrs	**2902 wafer passes**
15 Bp	45 hrs	**4352 wafer passes**
20 Bp	60 hrs	**5803 wafer passes**
25 Bp	75 hrs	**7254 wafer passes**
30 Bp	90 hrs	**8705 wafer passes**
35 Bp	105 hrs	**10156 wafer passes**

Table I. Predicted productivity increase with GLX.[7]

5. THE FUTURE OF GAS MANAGEMENT

Although GLX™ has achieved its goal of a large increase in light source availability, Cymer continues its commitment to further improvements. In the immediate future, GLX can be enhanced through additional tuning and research to provide even longer gas lives. This can be achieved through even more advanced signal processing and control algorithms that can compensate for the wearing of modules, long term signal drift, and uncertainties in end-user facilities and usage patterns.

Also, recall that GLX is designed to operate over 1 billion pulse intervals, regardless of the time taken to reach this interval. This performance-based method enables GLX to be enhanced simply by monitoring the laser more closely to determine the refill requirements. The need for a refill would be based solely on the laser's actual performance, rather than on a given time period. This so-called "predictive gas life" is a technology that Cymer is pursuing (reference 5).

6. CONCLUSIONS

As productivity demands on leading edge scanners increase, improved light source availability is always a requirement, and will necessitate new methods to reduce downtime and standby time.

To meet these needs, Cymer has developed and deployed the Gas Lifetime eXtension™ (GLX™) control system GLX currently demonstrates more than a 10X decrease in laser unavailability due to gas refill events in several real and challenging production environments.

In creating GLX, Cymer integrated several complementary technical and process advancements, and employed new algorithm and signal processing techniques to maximize the benefit of these advancements. Complementing this effort,

[7] Wafer passes based on 130 wafers/hour, 93% availability, 80% utilization. Typical usage on 4 kHz systems is 15 billion pulses/year. Typical usage on 6 kHz system is 20 billion pulses/year. Usage at memory fabs is much higher.

Cymer has developed designs for longer life modules and best practices for rapid module exchange. The combination of these ensures minimal impact to the light source availability budget.

By continually widening the space of possible solutions to meeting increasing demands, Cymer has achieved a significant and important advancement in the state of the art with GLX. Further improvements are anticipated both short-term and long-term, and Cymer's ongoing efforts to increase light source performance and reliability have been demonstrated throughout its history.

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